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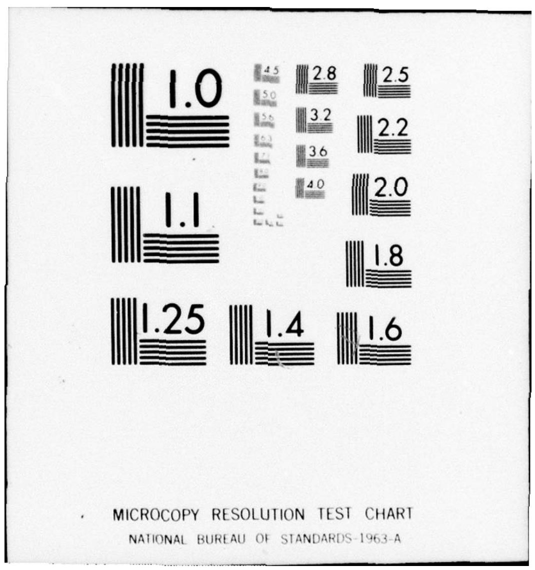
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For too long ~~the diver has~~ (divers have) been asked to compensate for inadequately designed equipment. There has been little human factors assessment of diving equipment and little systematic human engineering research directed toward improving diving equipment. In recent years, the Behavioral Sciences Department (at this) at the Naval Medical Research Institute, in cooperation with the U.S. Navy Experimental Diving Unit and the Performance Physiology Laboratory of the University of California at Los Angeles, has engaged in a series of human

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engineering studies in diving. ~~Based on these studies, we believe~~ a combination of physiological measures, biomechanical dynamic anthropometric measures, and underwater performance assessment (appears to provides the most efficient way of approaching diver performance. The physiological cost of the equipment, the impact of the equipment on the diver's performance, and the diver's ability to work under varying environmental conditions still needs considerable research investigation.

In this report the human bioengineering and performance physiology techniques outlined above are ~~will be~~ discussed; recommendations are ~~will be~~ made for further systematic cooperative research with other laboratories.

1473B

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HUMAN FACTORS AND DIVING EQUIPMENT DESIGN

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Yamaguchi-san, Miller-san, Otomodachi soshite Okyakusamatachi: kono jūyo na kaigi ni shuseki suru koto wa watakushi no mottomo meiyo to suru tokoro desu. Kono Tokyo to, International Ocean Exposition '75 wa takusan kaiyōgaku ni kōken suru desho. Kono kaigi no kaisai o iwatte, omedetoo gozaimasu to mōshi agemasu!

Sate, watakushi wa chotto Nihongo o hanashitai desu. Watakushi wa Nihongo no seito desu: sukoshi dekimasu. Nihongo wa kirei na kotoba desu: gaijin niwa fukuzatsu na kotoba desu, ne? Kyo wa, watakushitachi no chosa a shirasemasu. Watakushi no kenkyujo dewa sensuifu no dogu ya seiri o chōsa shimasu. Sukoshi wa, sensuifu no ningen-kogaku no chosa mo shimasu. Kore wa tama ni shika miraremasen: motto miru chance ga aru deshō. So omoimasu.

Sensuifu no shigoto mata wa seiri ni tekishita, sensuifu no sōgu ya sagyo-i no tadashii rikai ga arimasen. Sorede, takusan jiko o okoshimasu. Sensuifu ga byoki ni narimasu. Watakushitachi wa sensuifu o mushi shimasen. Watakushi no kenkyujo no chosa dewa ichi kiatsu desu. Umi no wa shichi kiatsu made desu. Korekara watakushitachi no chosa o hōkoku shimasu. Korekara watakushi wa Eigo o hanashimasu. Domo arigato gozaimashita!

INTRODUCTION

The human-engineering research to be described is drawn from a series of collaborative studies between the Behavioral Sciences Department at the Naval Medical Research Institute in Bethesda, Maryland, and the Performance Physiology Laboratory at the University of California at Los Angeles (Armstrong, Bachrach, Conda, Holiman, and Egstrom, 1974; Bachrach and Egstrom 1974; Bachrach, Egstrom and Blackmun 1975). Recognizing that there has been very little systematic study of the human engineering of diver equipment, investigators from these laboratories embarked on a series of analyses of diving equipment and performance, initially developing quantitative methods for such an analysis.

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[1] Chairman, Behavioral Sciences Department, Naval Medical Research Institute, National Naval Medical Center, Bethesda, Maryland. Supported by Naval Medical Research and Development Command, Navy Department, Research Task No. MPN10.03.2040DAC9. The opinions and statements contained herein are the private ones of the writer and are not to be construed as official or reflecting the views of the Navy Department or the naval service at large.

Using these quantitative methods, a biomechanical analysis and comparison was made of two diving systems, (1) the standard U.S. Navy diving system, the hard-hat Mark V (Fig. 1) (which is a possible replacement for the Mark V); and (2) the prototype Mark XII (Fig. 2). In the design of the Mark XII, one of the presumed advantages was its greater flexibility over the standard Mark V. Therefore, one of the major approaches was to develop (under Dr. Glen Egstrom's supervision) a biomechanical analysis of the two systems, using 14 measures based on dynamic anthropometry and drawn from movements actually performed by divers in underwater work (Fig. 3). This technique involved functional measurements concerned with the quantitative assessment of joint-angle changes and range of motion while divers were performing volitional movements. To assess the impact of the diving systems themselves on diver movement, a swimsuit baseline was taken in each system, followed by a dry and wet analysis of both systems. The basic concept was that the diving suit itself would impose certain external mechanical limitations on the normal internal mechanical stops expected in physical motion.

A major finding was that the prototype Mark XII allowed more movement for two important arm movements: shoulder joint abduction and shoulder joint flexion. In most of the 14 measures, the flexibility of the Mark XII was clearly demonstrated.

Following the laboratory and tank biomechanical analysis of the two diving systems, an evaluation was carried out in the open sea off Barber's Point in Hawaii in 60 feet of water. Several performance tasks were used, including the Enerpac cutting task (Quirk 1974); a self-contained load-handling lift pontoon (Conda and Armstrong 1973); and the UCLA pipe puzzle (Weltman, Egstrom, Willis, and Cuccaro 1971).

The UCLA pipe puzzle is a standardized assembly task in which a team of divers is required to put together a "real world" pipe assembly. This task has been used by Dr. Egstrom and his group in a variety of diving situations and has proved to be an effective measure of various types of performance.

In this evaluation, work on the pipe puzzle was correlated with heart rate measures accomplished by an acoustic telemetry system (Kanwisher, Lawson, and Strauss 1974) while the diver was performing in the water. This correlation of physiology and performance is a crucial one--to know the kind of work the diver is engaged in, the physiological cost of this work, and the systems and equipment the diver is using. This information is essential for dive planning, diver efficiency, and diver safety.

In the open-sea evaluation, the Mark V diving system appeared to produce more physiological strain, as seen in one diver who showed a heart rate of 184 beats a minute, suggesting marked effort. Yet this diver's resting heart rate on the deck of the diving barge was around 80 beats per minute, and he did not peak higher than 152 beats per minute in the Mark XII. These data suggest that the Mark V itself requires more physiological effort, a finding which needs further evaluation. Again, the correlation of heart rate and performance appears to be a very important source of information to assess diver work and equipment.

Another finding in assessing the two systems was that the divers performing the task assembly on the UCLA pipe puzzle in the open water required longer times to complete the task in the Mark V--suggesting that the higher degree of mobility generally found in the Mark XII allowed for more efficient performance.

UNDERWATER PERFORMANCE-ASSESSMENT TASK

Another product developed through the collaborative efforts of these two laboratories is a standardized underwater performance-assessment task, the SP^2, which provides further quantification of diver work and physiology. The UCLA pipe puzzle has been an effective underwater assessment technique, but a smaller task assembly is required that can be used in the wet pots of hyperbaric chambers and in the open sea for further assessment of diver performance under deep pressure.

The task is a conceptual derivation of the UCLA pipe puzzle. It (Fig. 4) is made up of seven assembly procedures that can be modified to suit a given situation; each task can be performed in three different work positions (standing, kneeling, lying down) and is limited to a 10-minute completion time. The task allows for performance measures ranging from fine coordination to dynamic strength. In this way human-engineering components in diving equipment can be assessed and correlated with physiological cost of work and impact of equipment under varying water and hyperbaric conditions.

HUMAN FACTORS ANALYSIS OF A HYPERBARIC FACILITY

Thusfar human factors considerations in the development of diving equipment have been stressed. These human factors considerations are also essential in the planning of a hyperbaric research facility. Such a facility is currently under construction as a component of the Naval Medical Research Institute at Bethesda, Maryland. This laboratory will provide a hyperbaric complex capable of simulating various diving conditions to a maximum depth of 3300 fsw. At this time, full-scale mock-ups of the facility have been developed and a detailed human-engineering analysis is underway.

Research has shown that man's performance efficiency is directly influenced by work-space design and layout. The need then to assess the new chamber complex and its associated control consoles would be of high priority since the control consoles present the greatest concentration of information for the chamber operators, and as such, present the greatest potential for operator error. Too, the chamber complex itself represents a restricted area where small groups of men will be confined for periods of up to 90 days. Often these personnel will be required to perform several functions in a relatively short period of time; a poorly arranged chamber interior could easily cause a portion of the experimental procedures to be aborted. Therefore, system design limitations must be considered for chamber-crew work and habitability during normal operation or under emergency conditions.

A set of guidelines developed by McCormick (1970) for the design of work space is based on the operational importance of a component and its frequency of use, functional relationship to the system, and sequence of use. Another set of principles, which were developed by VanCott and Kinkade (1972) and are more applicable to overall arrangement of a large area, lists: functional grouping (and the need for consistency between similar groupings); equitable workload distribution, which applies to distribution of workload among multiple operators as well as distribution between hands and feet for a single-operator (i.e. primary and secondary control functions are allocated to the hands and simple or tertiary functions to the feet); anthropometric differences, which would consider the anthropometric data within the 5th and 95th percentile range of the user population and thereby set limits that would allow for adjustable range (such as the forward-backward adjustment in automobile seats); and anticipation of safety hazards, which is preparation for emergency actions.

Visual, auditory, and tactile presentation of information must be assessed as it relates to control design (i.e. gases, meters, warning lights; buzzers, horn, or bells). Chapanis (1959, 1965) and VanCott and Kinkade (1972) provide useful guidelines in the human-engineering design of man-machine communications. The importance of the control consoles was stressed earlier; for these reasons, it would be critical to select the best possible control system to achieve the most effective man-machine performance.

CONCLUSION

The human factors involved in the development of diving equipment (and systems) must be considered--that is, the type of work and physiological effects of that work on the diver using the particular equipment. For too long a period the diver has been asked to compensate for inadequacies in diving gear. It is time to provide the scientific bases for assessing the diver's tools and equipment to make him a more effective and safe underwater performer. It is also time to provide assessment of procedures and equipment for the chamber operator so that he, too, may perform in a safe and effective manner.

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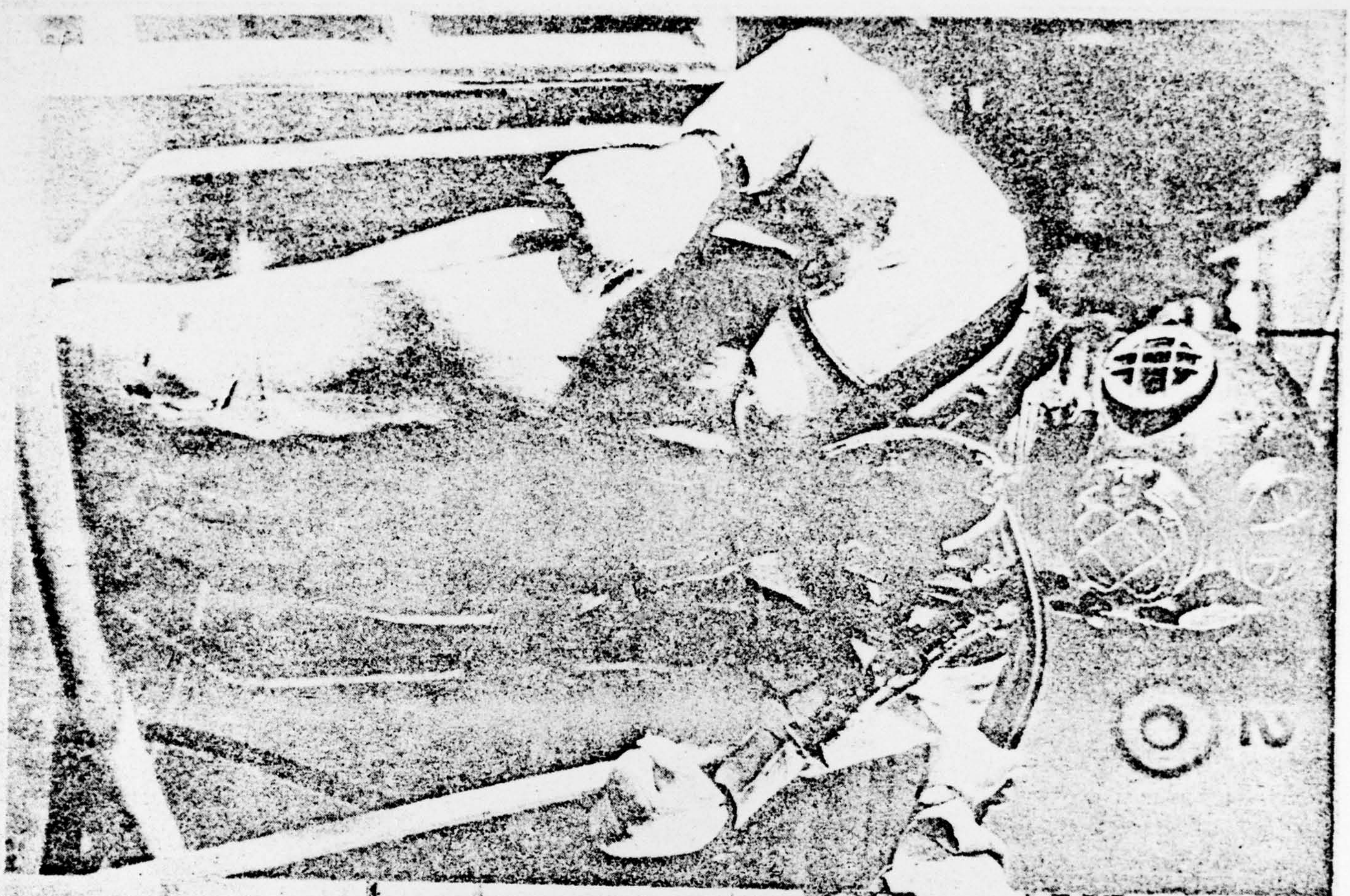
FIGURE LEGENDS

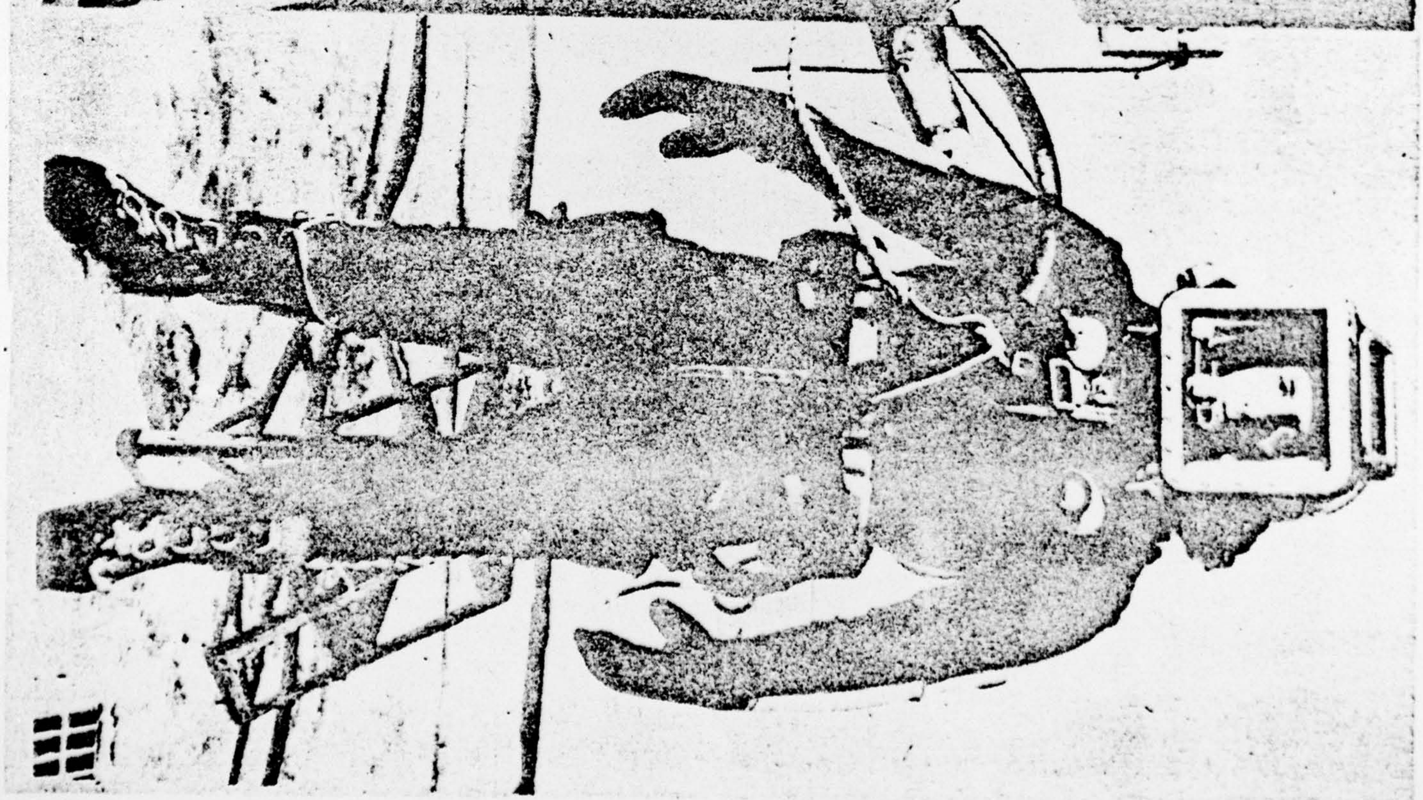
Fig. 1. Mark V diving dress.

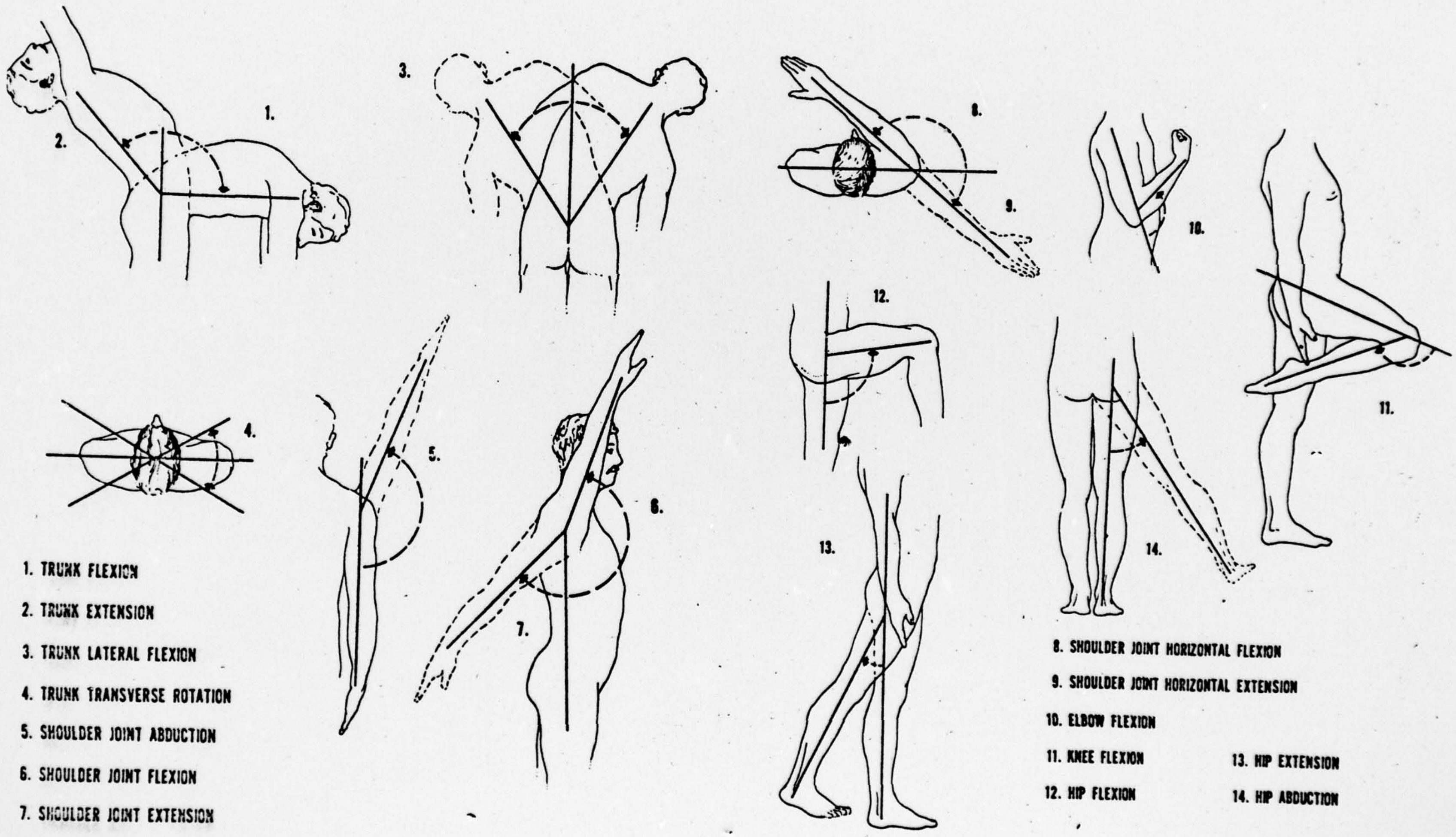
Fig. 2. Mark XII diving dress.

Fig. 3. Fourteen biomechanical measures.

Fig. 4. Diagram of SP^2, Underwater Performance Task.







1. TRUNK FLEXION
2. TRUNK EXTENSION
3. TRUNK LATERAL FLEXION
4. TRUNK TRANSVERSE ROTATION
5. SHOULDER JOINT ABDUCTION
6. SHOULDER JOINT FLEXION
7. SHOULDER JOINT EXTENSION
8. SHOULDER JOINT HORIZONTAL FLEXION
9. SHOULDER JOINT HORIZONTAL EXTENSION
10. ELBOW FLEXION
11. KNEE FLEXION
12. HIP FLEXION
13. HIP EXTENSION
14. HIP ABDUCTION

UNDERWATER WORK TASK SP²